National Aeronautics and
Space Administration

ANNUAL HIGHLIGHTS *of* RESULTS *from the* INTERNATIONAL SPACE STATION

October 1, 2015 – October 1, 2016

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Product of the International Space Station Program Science Forum

This report was developed collaboratively by the members of the Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), National Aeronautics and Space Administration (NASA), and the Roscosmos State Corporation for Space Activities (Roscosmos).

The highlights and citations in this report, as well as all the International Space Station (ISS) results and citations collected to date can be found at: https://www.nasa.gov/stationresults.

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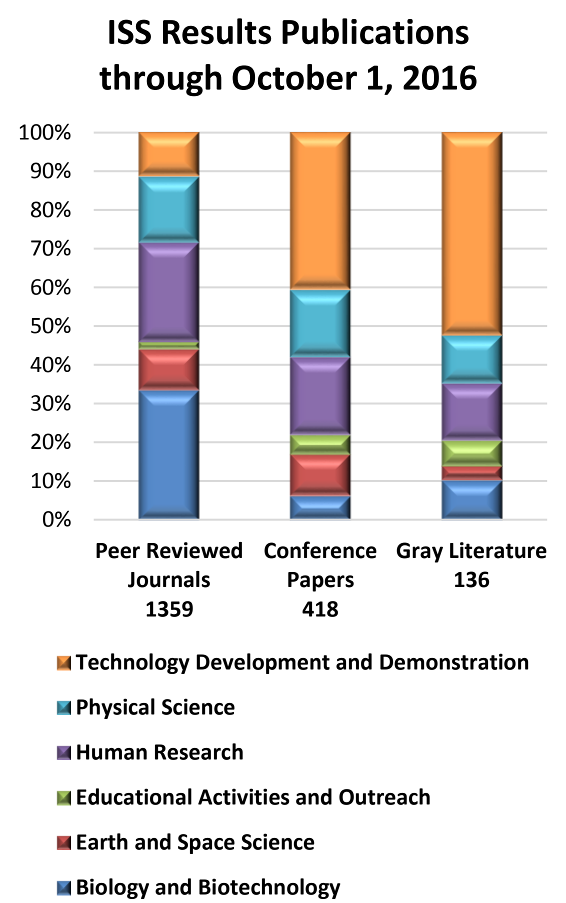
Cover:
ISS crewmember Kate Rubins works on Selectable Optical Diagnostics Instrument (SODI) Diffusion Coefficient Mixture (DCMix) installation inside the station's Microgravity Science Glovebox (MSG). The MSG is one of the major dedicated science facilities inside the Destiny laboratory and provides a sealed environment for conducting science and technology experiments (ISS049E002652).

Annual Highlights of Results from the International Space Station

INTRODUCTION

To date, research on the International Space Station (ISS) has helped answer scientific questions ranging from "How do fluids flow in space?" to "What are the origins of the universe?", and the science and technology returns have grown at a steady pace. The on-orbit international crew have been busier than ever performing research and technology development activities for use on Earth and in space. As of October 1, 2016, more than 2000 investigations were conducted across the international partnership resulting in more than 1900 publications in journals, conferences, and other gray literature (such as magazines, DVDs, and patents).



This report is intended to provide an overall highlight of research results published from October 1, 2015 to October 1, 2016 from investigations operated on the ISS. These results represent the research of approximately 500 scientists around the world for investigations sponsored by the National Aeronautics and Space Administration (NASA), the Roscosmos State Corporation for Space Activities (Roscosmos), the Japanese Aerospace Exploration Agency (JAXA), the European Space Agency (ESA), and the Canadian Space Agency (CSA). Like a typical laboratory on Earth, the logistics of the ISS allows for many investigations to be carried forward over several ISS crew expeditions, enabling repeated experimentation and data collection important for answering critical research questions. Impacts of these results reach beyond the field of space research into traditional areas of science in multidisciplinary ways.

From October 1, 2015 to October 1, 2016, 106 publications were collected as results for investigations operated on the ISS, with the majority representing Biology and Biotechnology and Human Research. This report will share some important highlights of the ISS results published in that timeframe, as well as the complete listings of the ISS results that benefit humanity, contribute to scientific knowledge, and advance the goals of space exploration for the world.

The ISS Program Science Office has a team of professionals dedicated to continuously collecting and archiving research results from all ISS utilization activities across the partnership at www.nasa.gov/iss-science. The database captures the ISS experiment summaries and results, and includes citations to the publications and patents as they become available. The team mines publications from the ISS research and technology development through many ways, including these examples listed below:

- keyword searches with various tools and search engines
- databases such as AIAA, IEEE, IngentaConnect, JSTOR, J-STAGE, ScienceDirect, Wiley
- Web of Science
- conference proceedings
- science networks such as ResearchGate
- email alerts from systems such as Pubmed, Google Scholar, Nature Partner Journal-Microgravity
- NASA Taskbook and others
- ISS investigator and international partner websites
- personal email exchanges with ISS investigators and international partners

This team also tracks and shares the article citations, impact factors and eigenfactors across the ISS partnership. The eigenfactor score is intended to measure the importance of a journal to the scientific community, by considering the origin of the incoming citations, and is thought to reflect how frequently an average researcher would access content from that journal. However, the eigenfactor score is influenced by the size of the journal, so the score doubles when the journal doubles in size (measured as number of published articles per year). For the time period of October 1, 2015 to October 1, 2016, 7 ISS results have been published in 3 of the top 5 journals by eigenfactor. The impact factor, or journal impact factor, of an academic journal is a measure reflecting the yearly average number of citations to recent articles published in that journal. It is frequently used as a measure for the relative importance of a journal within its field; journals with higher impact factors are often deemed to be more important than those with lower ones. Impact factors are calculated yearly for those journals that are listed in the Journal Citation Reports.

2015 – 2016 ISS Publication in the Top 5 Global Journals		
Journal (# of ISS articles)	**Impact Factor**	**Eigenfactor**
PLOS One (4)	3.057	1.81924
PNAS (1)	9.423	1.32650
Physical Review Letters (2)	7.645	0.82028

From October 2015 to October 2016, 7 scientific publications from the ISS have been in the Top 5 journals ranked by Eignefactor as reported by 2015 Journal Citation Reports®, Clarivate Analytics, 2017, along with the journal's impact factor. Missing from the list of top 5 above are Science and Nature (there were no ISS publications in Science or Nature for this timeframe).

All information pertaining to ISS investigations across the ISS international partnership is continuously updated at http://www.nasa.gov/iss-science, and in particular, publications of the ISS results can be found at http://www.nasa.gov/stationresults. As of October 1, 2016, over 1300 journal publications describe ISS research since the first ISS investigation began in 1998. Non-journal publications resulting from ISS utilization include 59 patents and over 400 conference proceedings.

Results from the ISS have yielded updated insights into how to better live and work in space, such as addressing radiation effects on crew health, combating bone and muscle loss, improving designs of systems that handle fluids in microgravity, and how to most efficiently maintain environmental control.

Results from the ISS also have Earth-based applications, including understanding our climate, contributing to the treatments of disease, improving on existing materials, and inspiring the future generation of scientists, clinicians, engineers, technologists, mathematicians, explorers, and artists.

Results from the ISS can provide new contributions to the body of scientific knowledge in the areas of physical sciences, life sciences, and Earth and space sciences that advances scientific discoveries in multidisciplinary ways.

Publication Highlights: Biology and Biotechnology

The ISS laboratories enable scientific experiments in the biological sciences that explore the complex responses of living organisms to the microgravity environment. The lab facilities support the exploration of biological systems ranging from microorganisms and cellular biology to integrated functions of multicellular plants and animals. Several recent biological sciences experiments have facilitated new technology developments that allow growth and maintenance of living cells, tissues, and organisms.

Discovery Benefits for Humanity

NASA's **Commercial Biomedical Testing Module-3: Assessment of Sclerostin Antibody as a Novel Bone Forming Agent for Prevention of Spaceflight-induced Skeletal Fragility in Mice (CBTM-3-Sclerostin Antibody)** investigation shows that after a 13-day stay in microgravity, mice lost a significant amount of body weight and redistributed lipids (fats) to the liver. Spaceflight also induced a loss of retinol (also known as Vitamin A) and a change in markers associated with remodeling of the extracellular matrix (the support structure for liver cells). Taken together, these results provide insight into liver metabolism and function in space that had not previously been studied, enabling new research pathways to investigate the risk of spaceflight on progressive liver damage and resulting fatty liver disease.

Spaceflight-induced bone loss has been studied for almost as long as humans have explored space, and many studies are ongoing on the ISS in an effort to better understand this risk to astronaut health. The CBTM-3 investigation provided new insights into bone remodeling of non-weight bearing bone by finding that the mandibular (jaw) bones of mice flown in space for 2 weeks undergo active skeletal changes, including bone loss. Additionally, investigators propose that factors associated with spaceflight such as elevated carbon dioxide levels, vascular changes, and elevated intracranial pressure may be important factors affecting the remodeling process of non-weight bearing bones in the head.

STS-118 Mission Specialist Tracy Caldwell and Pilot Charles Hobaugh observing the Animal Enclosure Modules (AEMs) in the Middeck of the Space Shuttle Endeavour (S118E09327).

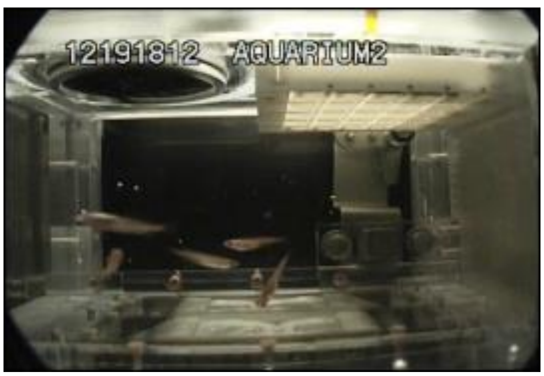
Jonscher KR, Alfonso-Garcia A, Suhalim JL, Orlicky DJ, Potma EO, Ferguson VL, Bouxsein ML, Bateman TA, Stodieck LS, Levi M, Friedman JE, Gridley DS, Pecaut MJ. Spaceflight activates lipotoxic pathways in mouse liver. *PLOS ONE*. 2016;11(4): e0152877. DOI: 10.1371/journal.pone.0152877. PMID: 27097220.

Ghosh P, Stabley JN, Behnke BJ, Allen MR, Delp MD. Effects of spaceflight on the murine mandible: Possible factors mediating skeletal changes in non-weight bearing bones of the head. *Bone*. 2016;83:156-161. DOI: 10.1016/j.bone.2015.11.001. PMID: 26545335.

Discovery

JAXA's **Medaka Osteoclast** investigation studied the behavior and physiological changes of the Japanese medaka (*Oryzias latipes*), a fish species commonly used for scientific research because of its transparent body enabling fluorescent observation and live-imaging of the internal body.

Scientists studied the medaka's cellular activities of bone formation and resorption in the gravity-sensitive pharyngeal region, which contains hundreds of teeth in the adult fish, and where many osteoclasts (cells that break down bone tissue) are found.



Video Screen Shot of Medaka in the Aquatic Habitat onboard the ISS (JAXA image).

The fish became accustomed to swimming in microgravity by displaying unique behaviors such as upside-down, vertical, and tight-circle swimming. Additionally, investigators found that the mating behavior at day 33 in microgravity was not different from that on Earth. Interestingly, the fish tended to become motionless at day 47, suggesting reduced muscle movement.

Investigators found that tooth development was normal on the ISS, but over the 56 days in microgravity, the mineral density of the upper pharyngeal bone and the tooth region decreased by about 24%, along with an increase in osteoclast volume compared to ground control fish. In October 2015, scientists published in the journal *PLOS ONE* that some genetic changes in tissue from the brain, eye, liver, and intestine were seen, and the intestine appeared to be most sensitive to microgravity. No significant gene changes were detected in ovaries or testes. Microgravity slightly disrupted egg creation in these fish but there was no delay in body growth and maturation. These results suggest that there may be a common immune-regulatory and stress response exhibited during spaceflight, contributing to the understanding of the mechanisms behind bone density and organ tissue changes in space.

Murata Y, Yasuda T, Watanabe-Asaka T, Oda S, Mantoku A, Takeyama K, Chatani M, Kudo A, Uchida S, Suzuki H, Tanigaki F, Shirakawa M, Fujisawa K, Hamamoto Y, Terai S, Mitani H. Histological and transcriptomic analysis of adult Japanese medaka sampled onboard the International Space Station. *PLOS ONE*. 2015;10(10):e0138799. DOI: 10.1371/journal.pone.0138799. PMID: 26427061.

Chatani M, Morimoto H, Takeyama K, Mantoku A, Tanigawa N, Kubota K, Suzuki H, Uchida S, Tanigaki F, Shirakawa M, Gusev OA, Sychev VN, Takano Y, Itoh T, Kudo A. Acute transcriptional up-regulation specific to osteoblasts/osteoclasts in medaka fish immediately after exposure to microgravity. *Scientific Reports.* 2016 December 22; 6: 39545. DOI: 10.1038/srep39545. PMID: 28004797.

†Chatani M, Mantoku A, Takeyama K, Abduweli D, Sugamori Y, Aoki K, Ohya K, Suzuki H, Uchida S, Sakimura T, Kono Y, Tanigaki F, Shirakawa M, Takano Y, Kudo A. Microgravity promotes osteoclast activity in medaka fish reared at the international space station. *Scientific Reports.* 2015 September 21; 5(14172). DOI: 10.1038/srep14172.

†This publication precedes the October 2015-2016 period of publication but is relevant to results reported here.

Exploration Discovery

Evaluation of the International Space Station Internal Environment (ISS Internal Environment) is an activity that occurs regularly on the ISS to evaluate air, water, and surface samples from the ISS to provide a baseline of the contaminant characterization onboard the ISS. All the partner agencies recognize the importance of crew health to mission success and are dedicated to maintaining the health of all crewmembers throughout all phases of ISS missions. Numerous air, water, and surface samples are collected by ISS crews on a regular basis. Many of these samples are cultured on board the ISS while others are preserved and returned to Earth for later analysis. The data obtained from environmental monitoring provides insight into the environmental contamination as astronauts continue to live and work on the ISS.

In 2015, scientists published in *PLOS ONE* the results of a study of exoenzyme lipase production in 9 different bacterial species isolated from the potable water system on the ISS. Bacterial exoenzymes are important contributors to ecosystem function, and lipases and proteases, in particular, play important roles in acquisition of nutrients, particularly in waste water systems and food processing. Scientists found that when the 9 different species were cultivated together, the robustness of the production of these exoenzymes increased, and the mechanism was likely due to the influence of bacterial communication between the species. The results indicate that the optimized exoenzyme production was generated at a level appropriate for maximizing limited nutrients available.

ISS crewmember Michael Barratt, sampling from the Potable Water Dispenser in the Destiny laboratory of the International Space Station during ISS Expedition 20 (ISS020E031565).

Willsey GG, Wargo MJ. Extracellular lipase and protease production from a model drinking water bacterial community is functionally robust to absence of individual members. *PLOS ONE.* 2015 November 23; 10(11): e0143617. DOI: 10.1371/journal.pone.0143617.

PUBLICATION HIGHLIGHTS: HUMAN RESEARCH

The ISS is being used to study the risks to human health that are inherent in space exploration. Many research investigations address the mechanisms of the risks—the relationship to the microgravity and radiation environments—and other aspects of living in space, including nutrition, sleep, and interpersonal relationships. Other experiments are used to develop and test countermeasures to reduce these risks. Results from this body of research are critical enablers for missions to the lunar surface and future Mars exploration missions.

Benefits for Humanity Exploration

Early evidence from the Canadian Space Agency's **Cardiovascular and Cerebrovascular Control on Return from ISS (CCISS) and the Cardiovascular Health Consequences of Long-Duration Spaceflight (Vascular)** investigations highlighted some of the individual variability of astronaut's responses related to regulation of arterial blood pressure and brain blood flow, as well as factors related to arterial stiffness and overall cardio-metabolic health.

Recent studies examined the spontaneous oscillations in blood pressure and heart rate to quantify the effectiveness of the arterial baroreflex response (the ability of the arteries to quickly respond to changes in blood pressure). The CCISS study revealed, in contrast to short-duration spaceflight, that the heart rate responses to changes in arterial blood pressure were well-maintained during long-duration spaceflight on the ISS. However, on return to Earth, the baroreflex response was significantly impaired with considerable variability between astronauts, potentially placing some of them at greater risk for dizziness and possible fainting. The study also found that the heart rate response during periods of normal daily activities while in space were similar to pre-flight but importantly the astronauts had a marked reduction in overall physical activity while in space which could influence key aspects of cardiovascular health with potential long-term consequences.

Regulatory mechanisms are essential for continuous supply of oxygenated blood to the brain. The results of the CCISS study indicated impairment of dynamic cerebrovascular autoregulation and CO_2 reactivity in astronauts on return to Earth. The chronic elevations in blood pressure in the brain while in space, compared to the normal upright posture on Earth, reductions in daily physical activity, and the constant exposure to slightly elevated levels of CO_2 during long-duration spaceflight might have

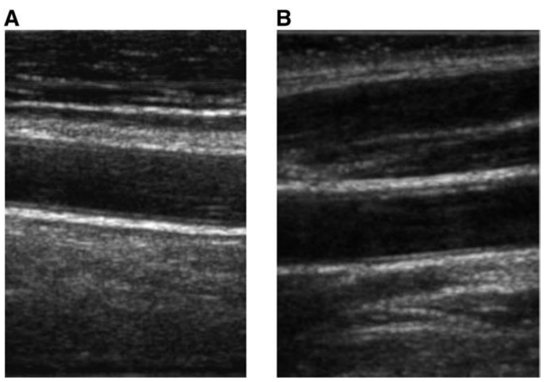
ISS crewmember Jeff Williams preparing blood for centrifugation for the Vascular study of cardio-metabolic health during spaceflight (ISS022E091397).

impaired the ability of the blood vessels of the brain to respond to changes in arterial blood pressure and CO_2.

Recent results of the Vascular study confirmed an increase in carotid artery stiffness indicators in male and female astronauts on return from 6 months on the ISS. The magnitude of increased stiffness was similar to changes expected with 10 to 20 years of normal aging. Mechanisms underlying the changes in artery structure and function might relate to the higher blood pressure in the head and neck without daily exposure to gravity in an upright posture, as well as to the overall reduction in physical activity. Potential health impacts of long periods of sedentary-like behavior in astronauts was observed in the development of insulin resistance in male and female astronauts during spaceflight. These discoveries have led to new studies to assess the magnitude of insulin resistance and explore appropriate countermeasures to maintain cardio-metabolic health, which have benefits to both space exploration and to better addressing cardiovascular conditions on Earth.

Hughson RL, Robertson AD, Arbeille P, Shoemaker JK, Rush JW, Fraser KS, Greaves DK. Increased post-flight carotid artery stiffness and inflight insulin resistance resulting from six-months spaceflight in male and female astronauts. *American Journal of Physiology: Heart and Circulatory Physiology*. 2016 March;310(5):H628-H638. DOI: 10.1152/ajpheart.00802.2015. PMID: 26747504.

Many factors associated with long-term spaceflight have been shown to cause changes to the cardiovascular system, both functionally and structurally. Some of those factors can include redistribution of body fluids, decreased physical movement, and the inherently stressful nature of the environment. To better understand the extent of change and its potential permanency, investigators sponsored by ESA implemented the **Vascular Echography (Vessel Imaging)** investigation.
This study sought to determine the effects



Example images of the longitudinal view of the common carotid artery A) preflight and B) in flight. Images obtained with the longitudinal view of the artery were used for the measurement of IMT (Phillippe Arbeille image).

of 6 months of microgravity exposure on carotid artery (the main source of blood flow to the head) and femoral artery diameter (the main source of blood supply to the lower limbs) and wall thickness. Astronauts were trained to use ultrasound techniques on the ISS to provide images of the vessels, which were compared to pre-flight and post-flight images. The experiments revealed data on the extent of vascular dilation and blood pooling in different areas of the body through long-term exposure to weightlessness. For example, the jugular vein, which brings blood from the head back toward the heart was measured as 3 to 4 times larger in orbit compared to pre-flight, and there were further increases measured in the volume of the veins studied in the pelvic and abdominal regions. There were, however, decreases measured in the calf veins studied. The lower limbs are coincidentally the most prone to the greater percentage loss of muscle and bone mass. Similarly, superficial femoral artery intima-media thickness (IMT) was increased during the flight but returned to pre-flight levels 4 days post-flight. Interestingly, an increase in carotid and femoral IMT was also observed during the Mars 500 space analog mission, during 520 days of confinement (1 G gravity, no fluid redistribution, no radiation, no restriction in food intake and exercise). Overall, given that these 2 environments are different in all aspects except for high levels of stress, investigators suggest that stress may be a major factor on arterial inner wall thickness. These are indications that some level of remodeling occurs during spaceflight, which may have implications on overall crew health in space.

Arbeille P, Provost R, Zuj KA. Carotid and femoral artery intima-media thickness during 6 months of spaceflight. *Aerospace Medicine and Human Performance*. 2016;87(5):449-453. DOI: 10.3357/AMHP.4493.2016.

The **Pilot** investigation, sponsored by Roscosmos, was performed on the *Mir* space station, the International Space Station, and during several ground-based space analogs, after Russian investigators found that *Mir* cosmonauts lost proficiency in manual docking techniques after a break in training of 90 days. On the *Mir*, manual control of redocking flights was a routine procedure, and is still used today on the ISS. Training and skill maintenance of manual control and docking of a spacecraft has historically been a fundamental part of a cosmonaut's training, and any degradation in performance has implications regarding overall mission safety. The Pilot experiment aimed to investigate cosmonaut's skill in and performance of manual docking of a Soyuz spacecraft on the space stations (*Mir* and ISS) during different stages of long-term spaceflights.

An experimental docking simulator challenged the cosmonauts with a series of docking flight tasks while evaluating their performance over time while on orbit. Overall, Pilot demonstrated that the performance level of Russian cosmonauts in hand-controlled docking of a spacecraft was found to be significantly improved on the ISS as compared to the *Mir* performances. This is likely because ISS-trained cosmonauts are offered more docking training sessions that also have a high number of flight tasks during a session. Investigators also noted that manual docking training may be most effective when implemented at the end of a mission if that is when the skill will be performed on orbit (rather than spread out over a period of several years).

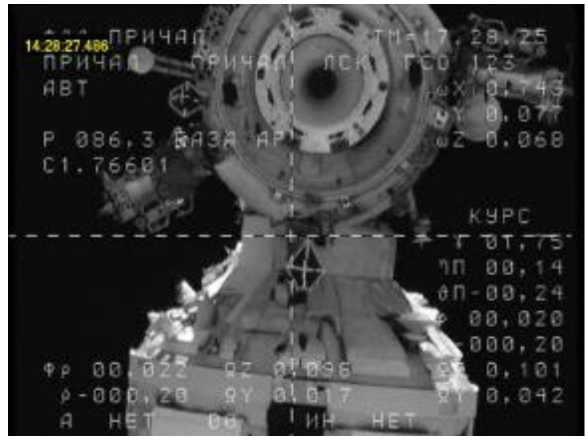


Image of a Progress vehicle docking with the ISS (ESA image, 238181).

Investigators suggest a training system that can identify weaknesses of the individual and adequately respond by suggesting the appropriate areas of training to improve the weaknesses. Studies such as Pilot are important for future exploration of space, as they seek to maintain crew health, safety, and mission success by assessing and addressing critical skill maintenance.

Johannes B, Salnitskiy VP, Dudukin AV, Shevchenko LG, Bronnikov SV. Performance assessment in the PILOT experiment on board space stations Mir and ISS. *Aerospace Medicine and Human Performance*. 2016;87(6):534-544. DOI: 10.3357/AMHP.4433.2016. PMID: 27208676.

Discovery Exploration

The Biomedical Analyses of Human Hair Exposed to a Long-term Spaceflight (Hair) investigation sponsored by JAXA examined the effect of long duration spaceflight on gene expression and trace element metabolism in the human body by analyzing human hair. It was the first study to evaluate the gene expression changes in astronauts at multiple time points in spaceflight. Actively dividing hair root cells can reveal a person's physical health, while the hair shaft can record the metabolic conditions of a person's living environment.

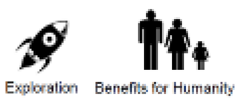
Hair samples that were collected from 10 crewmembers on the ISS showed increases in FGF18 and ANGPTL gene expression, which are genes usually associated with a temporary arrest in the hair growth cycle. Interestingly, females had a more stable expression of FGF18 than males in space, suggesting that female astronauts appear in this case to have a better response against the environmental effects of spaceflight. Some crewmembers also showed an increase in the expression of PCDH8, which could be a stress response, and on Earth, a loss of PCDH8 is known to promote oncogenesis in epithelial human cancers by disrupting cell to cell communication. Though it is not yet clear whether spaceflight actually does have a direct effect on hair growth, the results of this study do show that overall, spaceflight affects human hair follicle gene expression.

ISS crewmember Akihiko Hoshide prepares to take hair samples for the JAXA Hair investigation during ISS Expediton 33 (ISS033E018803).

Terada M, Seki M, Takahashi R, Yamada S, Higashibata A, Majima HJ, Sudoh M, Mukai C, Ishioka N. Effects of a closed space environment on gene expression in hair follicles of astronauts in the International Space Station. *PLOS ONE*. 2016;11(3):e0150801. DOI: 10.1371/journal.pone.0150801. PMID: 27029003.

PUBLICATION HIGHLIGHTS: PHYSICAL SCIENCES

Much of our understanding of physics is based on the inclusion of gravity in fundamental equations. Using a laboratory environment found nowhere else, the ISS provides the only place to study long-term physical effects in the absence of gravity, without the complications of gravity-related processes such as convection and sedimentation. This unique microgravity environment allows different physical properties to dominate systems, and these have been harnessed for a wide variety of investigations in the physical sciences.



Understanding combustion is crucial for both crew safety during future long-duration missions beyond low Earth orbit, and the safety of those on Earth. To advance space exploration efforts, testing how materials ignite and smolder in microgravity is essential for choosing everything for spacecraft design, from windowpanes to wire insulation, which will travel on longer-term missions to Mars or other destinations. NASA's **Burning and Suppression of Solids – II (BASS-II)** results contribute to the combustion models used in the design of fire detection and suppression systems in microgravity and on Earth.

During the BASS-II investigation, different solid spacecraft materials were tested to understand the efficiency with which they burn. Though researchers were not surprised to find that the flames converted the vast majority of the oxygen into carbon dioxide, they did find that different fuel samples, depending on different airflow conditions, yielded different ratios of carbon monoxide to carbon dioxide. In fact, most of the flames had much higher ratios of carbon monoxide to carbon dioxide than flames studied on Earth. Because breathing in carbon monoxide is much more dangerous than breathing in carbon dioxide, these findings indicate that materials burned on Earth that would not typically pose a risk to human health could pose a serious health risk in space.

Image taken during a BASS-II flame test (ISS038E049159).

Overall, to date BASS-II tests produced data on how ambient oxygen, ventilation, and fuel affect combustion and burning. Theoretical formulas and data on flame spread do not always match in normal gravity. With data from microgravity, scientists determined thin and thick fuel spread rates and a formula for transition from thin to thick fuels. The data allowed calculation of combustion completeness, heat release rates, and fuel-to-oxygen global equivalence ratios and supported theoretical models for quenching boundaries. Results will guide choice of materials for future spacecraft and advance fire detection and suppression in space and on Earth.

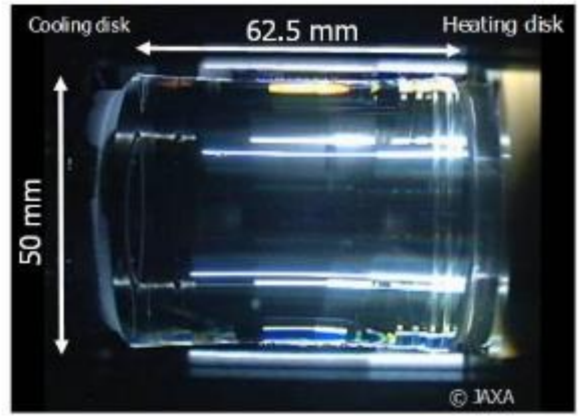
Bhattacharjee S, Simsek A, Miller FJ, Olson SL, Ferkul PV. Radiative, thermal, and kinetic regimes of opposed-flow flame spread: A comparison between experiment and theory. *Proceedings of the Combustion Institute.* 2016;36(2):2963-2969. DOI: 10.1016/j.proci.2016.06.025.

Zhao X, Liao YT, Johnston MC, Tien JS, Ferkul PV, Olson SL. Concurrent flame growth, spread, and quenching over composite fabric samples in low speed purely forced flow in microgravity. *Proceedings of the Combustion Institute*. 2016;36(2):2971-2978. DOI: 10.1016/j.proci.2016.06.028.

Bhattacharjee S, Laue M, Carmignani L, Ferkul PV, Olson SL. Opposed-flow flame spread: A comparison of microgravity and normal gravity experiments to establish the thermal regime. *Fire Safety Journal*. 2016;79:111-118. DOI: 10.1016/j.firesaf.2015.11.011.

Bhattacharjee S, Simsek A, Olson SL, Ferkul PV. The critical flow velocity for radiative extinction in opposed-flow flame spread in a microgravity environment: A comparison of experimental, computational, and theoretical results. *Combustion and Flame*. 2016;163:472-477. DOI: 10.1016/j.combustflame.2015.10.023.

Thermocapillary flow (Marangoni flow) is the movement of a liquid by using a temperature-dependent surface tension gradient, and can best be studied through the formation of liquid bridges to understand the fundamental nature of fluid behavior. A liquid bridge is a cylindrical mass of liquid held by surface tension between 2 solid discs. Thermocapillary convection is difficult to study on Earth through these highly-sensitive liquid bridges because gravity and convection limit the stability of the bridges. Therefore, JAXA's **Experimental Assessment of Dynamic Surface Deformation Effects in Transition to Oscillatory Thermocapillary Flow in Liquid Bridge of High Prandtl Number Fluid (Dynamic Surf)** investigation was performed on the ISS to best study the development of thermocapillary-induced convection. By observing and understanding how such fluids move, researchers can learn how heat is transferred in microgravity, and ultimately drive the design and development of more efficient fluid flow based systems and devices. During the implementation of the experiments, scientists saw large unexpected side-to-side liquid bridge oscillations as a result of 2 unanticipated shaking incidents in the ISS environment. When studying the unexpected oscillations more closely, the investigation team learned something new and valuable for implementing experiments on the sensitive liquid bridges: even the smallest perturbations in the environment (even in microgravity) can cause significant disruption to the bridge formation. They also discovered a key result of these disturbances that may be overlooked in most analyses of liquid bridges, even on Earth: it takes an unexpectedly long time for the liquid bridge to reach its maximum deformation (the disturbances last for a long time). These results provide researchers with an in-depth analysis of liquid bridge responses to very small perturbations, and pave the way for improved methods and analysis techniques in continued studies of liquid bridge formation in microgravity and on Earth.



Large liquid bridge of silicone oil (JAXA image).

Ferrera C, Herrada MA, Montanero JM. Analysis of a resonance liquid bridge oscillation on board of the International Space Station. *European Journal of Mechanics - B/Fluids*. 2016;57:15-21. DOI: 10.1016/j.euromechflu.2016.02.003.

PUBLICATION HIGHLIGHTS: TECHNOLOGY DEVELOPMENT AND DEMONSTRATION

Future exploration—the return to the moon and human exploration of Mars—presents many technological challenges. Studies on the ISS can test a variety of technologies, systems, and materials that will be needed for future Exploration missions. Some of the technology development experiments have been so successful that the hardware has been transitioned to operational status. Other experimental results feed new technology developments.

Exploration

Modern spacecraft orbiting Earth and other planets are equipped with advanced science instruments that collect large amounts of data, which can take a long time to send back. Optical communications uses laser beams to transmit data instead of radio waves. Laser beams are more narrowly focused than radio waves and can transmit data at a faster rate, but turbulence in Earth's atmosphere can distort such data transmission. To solve that distortion, researchers have developed adaptive optics (AO)—a system that corrects the received signal to compensate for distortions. This adjustment potentially increases the speed at which laser data can be transmitted and is particularly important when attempting to send data at high rates during times of high atmospheric turbulence.

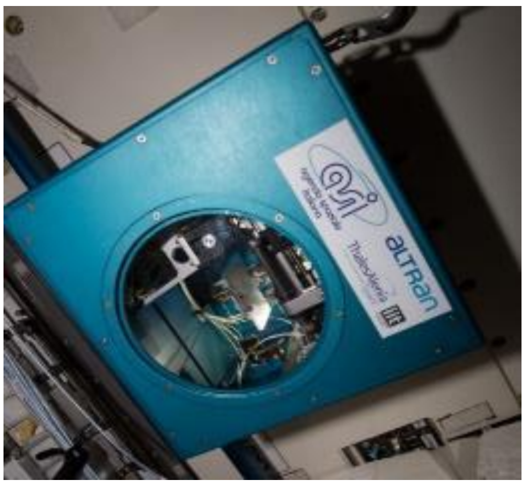
NASA's **Optical Payload for Lasercomm Science (OPALS)** on the ISS demonstrated the first ever use of an AO system to correct wave-front distortions induced by random atmospheric turbulence, to successfully send an optical downlink (a laser coded with digital communications) from the ISS in low Earth orbit (LEO) to the Jet Propulsion Laboratory's (JPL) Optical Communications Telescope Laboratory (OCTL) ground receiving station at Wrightwood, California.

The use of the AO to perform this correction on an optical link from the ISS with such a massive data platform in LEO underscores its critical role as a data transfer capability for future space missions, particularly when attempting to achieve high data rates for daytime operations when high levels of atmospheric turbulence are present. The results of the OPALS demonstration are the first to show that potential high data rate (multi-Gbps) space to ground optical communications are possible for operational use in future space-based data transfer systems.

OPALS investigation on the ExPRESS Logistics Carrier – 1 and the port solar array wings (ISS042E106460).

Wright MW, Morris JF, Kovalik JM, Andrews KS, Abrahamson MJ, Biswas A. Adaptive optics correction into single mode fiber for a low Earth orbiting space to ground optical communication link using the OPALS downlink. *Optics Express*. 2015;23(26):33705-33712. DOI: 10.1364/OE.23.033705. PMID: 26832033.

The **Portable On Board Printer 3D** from the Italian Space Agency (ASI) paves the way for a mature application of the selected additive manufacturing technologies on the ISS, and further developments for direct manufacturing in space. This investigation printed three-dimensional samples in space to provide information on how the material is deposed in microgravity (surface roughness, density and porosity of the deposed material, surface and internal defects, and mechanical properties).



Fabrication of the test object in the Portable on-Orbit 3D Printer (ISS046E031502).

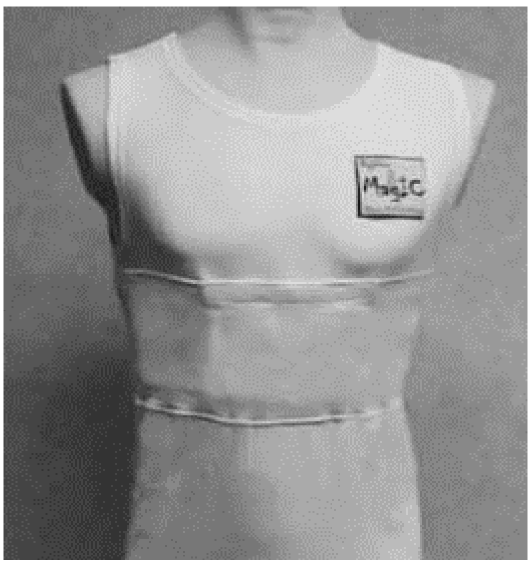
The main advantage derived from the use of additive manufacturing technology in space missions is a significant improvement of the maintenance logistics. Manufacturing items on-orbit as required can reduce the amount of spares needed on board. Raw materials required by these manufacturing processes can be stowed more efficiently than final items. Additive manufacturing technologies are key to reducing the volume and mass needed for successful long-duration exploration beyond Earth's orbit.

Musso G, Lentini G, Enrietti L, Volpe C, Ambrosio EP, Lorusso M, Mascetti G, Valentini G. Portable on orbit printer 3D: 1st European additive manufacturing machine on International Space Station. *Advances in Physical Ergonomics and Human Factors*. 2016;489. DOI: 10.1007/978-3-319-41694-6_62.

Exploration Benefits for Humanity

Wearable System for Sleep Monitoring in Microgravity (Wearable Monitoring) designed by ASI, aims to validate the applicability of a new smart garment (MagIC-Space) for the monitoring of vital signs during spaceflight.

The device can monitor a space explorer's autonomic nervous control, heart electrical and mechanical activity, skin temperature, and breathing patterns during sleep in microgravity.



The MagIC vest (Image courtesy of ASI).

Subject testing began in 2015 onboard the ISS, and the smart garment allowed all recordings to be made as planned and provided signals of good quality (~98% of the recorded data is available for the subsequent analyses).

The vest could become a new, unobtrusive monitor for a wide range of vital signs during sleep and waking hours. Most of its sensors and wires are embedded in the vest, making it easier to put on and more comfortable to wear, and allows uninterrupted monitoring during sleep.

Benefits for those on Earth could mean less complicated devices used to measure sleep patterns, and the prospect of monitoring patients in remote locations.

Di Rienzo M, Vaini E, Lombardi P. Wearable monitoring: A project for the unobtrusive investigation of sleep physiology aboard the International Space Station, *Computing in Cardiology Conference (CinC)*. 2015. DOI: 10.1109/CIC.2015.7408602.

PUBLICATION HIGHLIGHTS: EARTH AND SPACE SCIENCE

The presence of the space station in low-Earth orbit provides a unique vantage point for collecting Earth and space science data. From an average altitude of about 400 km, details in such features as glaciers, agricultural fields, cities, and coral reefs taken from the ISS can be layered with other sources of data, such as orbiting satellites, to compile the most comprehensive information available. Even with the many satellites now orbiting in space, the ISS continues to provide unique views of our planet and the universe.

The **Alpha Magnetic Spectrometer-02 (AMS-02)** is a state-of-the-art particle physics detector constructed, tested, and operated by an international team composed of 60 institutes from 16 countries and organized under the United States Department of Energy (DOE) sponsorship. The AMS-02 uses the unique environment of space to advance knowledge of the universe and lead to the understanding of the universe's origin by searching for antimatter, dark matter, and measuring cosmic rays.

Exterior view of the ISS with the AMS-02 visible in the foreground (ISS028E016134).

Experimental evidence indicates that our galaxy is made of matter; however, there are more than 100 hundred million galaxies in the universe, and the Big Bang theory of the origin of the universe postulates equal amounts of matter and antimatter were produced at the start. Theories that explain this apparent asymmetry violate other measurements. Whether or not there is significant antimatter is one of the fundamental questions of the origin and nature of the universe. The visible matter in the universe (stars) adds up to less than 5% of the total mass that is known to exist from many other observations. The other 95% is dark, either dark matter (which is estimated at 20% of the universe by weight or dark energy, which makes up the balance). The exact nature of both is still unknown. One of the leading candidates for dark matter is the neutralino. If neutralinos exist, they should be colliding with each other and giving off an excess of charged particles that can be detected by AMS-02. Any peaks in the background positron, anti-proton, or gamma flux could signal the presence of neutralinos or other dark matter candidates. Within its first 5 years of operation on the ISS, AMS has so far collected data from more than 90 billion cosmic rays and has published its major results in the journal *Physical Review Letters*. The latest AMS measurements of the positron spectrum and positron fraction, the antiproton/proton ratio, the behavior of the fluxes of electrons, positrons, protons, helium, and other nuclei provide precise and unexpected information on the production, acceleration, and propagation of cosmic rays. Any observations of an antihelium nucleus would provide evidence for the existence of larger antimatter accumulations. In a review article, “The First Five Years of the Alpha Magnetic Spectrometer on the International Space Station,” released by AMS principal investigator Samuel Ting, PhD, the following results are summarized from the first 5 years of AMS operations,:

- **Elementary Particles In Space:** AMS has observed that with a data set of 16,500,000 electrons and 1,080,000 positrons, the electron flux and positron flux display different behaviors in their magnitude and energy dependence. As a result, AMS data challenge previous theories by finding that spectral indices are not constant and that fluxes of electrons and positrons are different both in magnitude and in energy dependence.
- **Dark Matter and Elementary Particles in Space:** Positron fraction as measured by AMS shows a rise above the rate expected from cosmic ray collisions, and the positron flux (spectrum) and positron fraction exhibit a tendency to sharply drop off at high energies. Although overall, this positron data is in excellent agreement with the dark matter model predictions with a dark matter mass of ~1 TeV, it is also possible that these observations may be a result of typical physical phenomena such as pulsars. Interestingly, AMS has also studied the antiproton to proton ratio, and has found an excess in antiprotons (antiprotons are very rare in the cosmos) that cannot easily be explained as coming from pulsars. In 5 years of operations, AMS has found 349,000 antiprotons, and of these, 2200 have energies above 100 billion electron volts. This excess can more likely be explained by dark matter collisions or new astrophysics models rather than pulsars.
- **Nuclei in Cosmic Rays:** AMS contains 7 instruments with which to independently identify different elementary particles as well as nuclei. Helium, lithium, carbon, oxygen, and heavier nuclei up to iron have been studied by AMS. Studying these, AMS investigators suggest the age of cosmic rays in the galaxy is ~12 million years, and also provides data that is in agreement with the Kolmogorov turbulence model of magnetized plasma.
- **Antimatter in Cosmic Rays:** The Big Bang origin of the universe requires that matter and antimatter be equally abundant at the very hot beginning of the universe. The search for the explanation for the absence of antimatter in a complex form requires observation and analyses of anti-helium or heavier antiparticle events in cosmic rays. In 5 years, AMS has collected 3.7 billion helium events (charge Z = +2), but have observed a few Z = -2 events with mass around ^{3}He. Because these observations are so rare, more data from the AMS over the coming years is required to confirm the data suggesting these possible Z = -2 anti-helium events.

Aguilar-Benitez M, Cavasonza LA, Alpat B, Ambrosi G, Arruda MF, Attig N, Aupetit S. Antiproton flux, antiproton-to-proton flux ratio, and properties of elementary particle fluxes in primary cosmic rays measured with the Alpha Magnetic Spectrometer on the International Space Station. *Physical Review Letters*. 2016;117(9):091103. DOI: 10.1103/PhysRevLett.117.091103. PMID: 27610839.

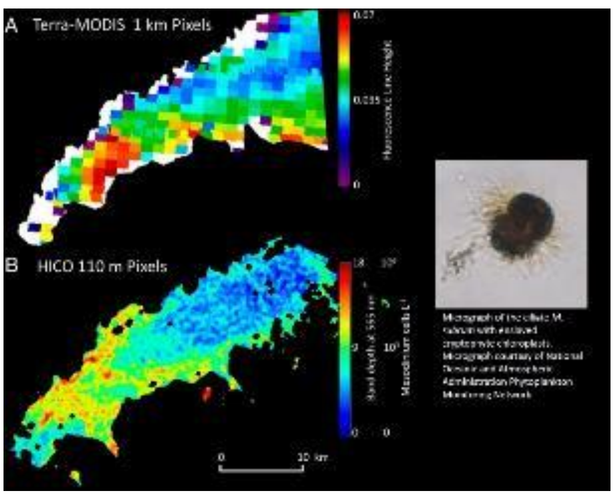
Aguilar-Benitez M, Cavasonza LA, Ambrosi G, Arruda MF, Attig N, Aupetit S, Azzarello P, Bachlechner A. Precision measurement of the boron to carbon flux ratio in cosmic rays from 1.9 GV to 2.6 TV with the Alpha Magnetic Spectrometer on the International Space Station. *Physical Review Letters*. 2016:117(23): 231102. DOI: 10.1103/PhysRevLett.117.231102. PMID: 27982618.

"The First Five Years of the Alpha Magnetic Spectrometer on the International Space Station" December 8, 2016. http://www.ams02.org/2016/12/the-first-five-years-of-the-alpha-magnetic-spectrometer-on-the-international-space-station/

Aguilar-Benitez M, Aisa D, Alpat B, Alvino A, Ambrosi G, Andeen K, Arruda MF. Precision measurement of the helium flux in primary cosmic rays of rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station. *Physical Review Letters*. 2015;115(21):211101. DOI: 10.1103/PhysRevLett.115.211101. PMID: 26636836.

Benefits for Humanity

The **HICO and RAIDS Experiment Payload - Hyperspectral Imager for the Coastal Ocean (HREP-HICO)** was the first spaceborne imaging spectrometer optimized to sample the coastal ocean. The sensor was launched to the ISS on September 10, 2009 and successfully operated until hardware failure during a solar storm ended its mission on September 13, 2014. HICO data, with sampling of 128 bands in the visible and near-infrared wavelengths, has given scientists an exceptional new view of the coastal ocean and the Great Lakes and provided a great new tool for managing these critical resources.



(A) Image of WLIS at a resolution of 1 km from the MODIS Terra sensor shows an elevated Chl a fluorescence patch on September 23, 2012, but the type of bloom cannot be distinguished from the limited spectral bands. (B) In contrast, hyperspectral HICO imagery from the International Space Station reveals characteristic yellow fluorescence due to phycoerythrin pigment within the enslaved chloroplasts of the ciliate M. rubrum. Dense and patchy near-surface blooms of this motile and actively photosynthesizing mixotrophic marine protist (>1 × 106 cells per liter) periodically dominate primary productivity in the region.

HICO images have been shown to provide a good means for estimating chlorophyll-a concentrations (an indicator of both healthy and harmful phytoplankton in the water) for a wide variety of coastal waters. During its 5 years in operation (2009-2014) HICO collected over 10,000 scenes from around the world. Each scene covered an area of about 30 miles by 125 miles, capturing features like river outflow plumes or algal blooms, enabling scientists to characterize and detect change in the environment of coastal regions. Across the world, HICO image targets have included areas such as the Yellow Sea near South Korea, the Florida Keys, and Azov Sea, Russia. Data from HICO was also used to characterize the oil spill resulting from the Deepwater Horizon oil rig explosion in the Gulf of Mexico, on April 20, 2010, and HICO data was also used to monitor harmful algal blooms in Lake Erie and other lakes and reservoirs. The United States Environmental Protection Agency (EPA) has also used HICO data to construct baseline algorithms for a mobile app designed to provide real-time water quality information to the public for US water bodies and coastal areas.

In 2015, HICO scientists published the role of HICO in documenting the species and extent of a large "red tide" bloom of *Mesodinium rubrum* microzooplankton in Long Island Sound, New York. This was the first time that plankton distribution and abundance were mapped using unique yellow fluorescent properties of its signature pigment phycoerythrin. Analysis showed that this was not actually a harmful algal bloom, but instead an important source of productivity in sound.

Dierssen H, McManus GB, Chlus A, Qiu D, Gao BG, Lin S. Space station image captures a red tide ciliate bloom at high spectral and spatial resolution. *Proceedings of the National Academy of Sciences of the United States of America*. 2015 December 1; 112(48): 14783-14787. DOI: 10.1073/pnas.1512538112. PMID: 26627232.

PUBLICATION HIGHLIGHTS: EDUCATIONAL ACTIVITIES AND OUTREACH

The ISS provides a unique platform for inspiring students to excel in science, technology, engineering, and mathematics. Station educational activities have had a positive impact on thousands of students by involving them in station research, and by using the station to teach them the science and engineering behind space exploration. To date, International Space Station research has involved over 40 million students and 3 million teachers around the world.

Benefits for Humanity

To prepare the next generation of space explorers to go on missions beyond low Earth orbit, space agencies around the globe have put into place programs to encourage students to study and pursue careers in the STEM fields of science, technology, engineering, and mathematics. The **Columbus Eye: Live Images from the ISS in the Classroom** raised student awareness of sustainable treatment of the Earth.

Screenshot of live imagery of the ISS streaming at https://eol.jsc.nasa.gov/ESRS/HDEV/

This investigation allowed students to observe Earth from the astronaut's perspective while applying remote sensing analysis tools utilizing the High Definition Earth Viewing (HDEV) camera (https://eol.jsc.nasa.gov/ESRS/HDEV/). To date, more than 1000 students and 70 teachers have been directly involved in this investigation alone. Lessons have also aired on television and radio, and visits to the website have reached more than 11,000 students. This investigation was developed by the University of Bonn and sponsored by the German Aerospace Center (DLR) Space Administration. The HDEV archive in Bonn maintains all downloaded videos since the end of 2014. Besides a continuous storage, the project selects some 'highlights' from the HDEV experiment which are published online. Like the HDEV live stream, they are freely available at the Columbus Eye portal www.columbuseye.uni-bonn.de.

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October 1, 2015 - October 1, 2016 ISS Research Results Publications (Listed by Category and Alphabetically by Investigation)

Biology and Biotechnology

Animal Enclosure Module (AEM) – Moyer EL, Dumars PM, Sun G, Martin KJ, Heathcote DG, Boyle RD, Skidmore MG. Evaluation of rodent spaceflight in the NASA animal enclosure module for an extended operational period (up to 35 days). *npj Microgravity*. 2016;2:16002. DOI: 10.1038/npjmgrav.2016.2.

Advanced Plant Experiment-Transgenic Arabidopsis Gene Expression System-Intracellular Signaling Architecture/Molecular Biology of Plant Development in the Spaceflight Environment (APEX-03-2 TAGES-Isa/CARA) – Ferl RJ, Paul A. The effect of spaceflight on the gravity-sensing auxin gradient of roots: GFP reporter gene microscopy on orbit. *npj Microgravity*. 2016;2:15023. DOI: 10.1038/npjmgrav.2015.23.

Biological Research in Canisters-16: Investigations of the plant cytoskeleton in microgravity with gene profiling and cytochemistry (BRIC-16-Cytoskeleton) – Johnson CM, Subramanian A, Edelmann RE, Kiss JZ. Morphometric analyses of petioles of seedlings grown in a spaceflight experiment. *Journal of Plant Research*. 2015;128(6):1007-1016. DOI: 10.1007/s10265-015-0749-0.

Biological Research in Canisters-18-1: Development of Multiple Antibiotic Resistance By Opportunistic Bacterial Pathogens During Human Spaceflight (BRIC-18-1) – Fajardo-Cavazos P, Nicholson WL. Cultivation of Staphylococcus epidermidis in the human spaceflight environment leads to alterations in the frequency and spectrum of spontaneous rifampicin-resistance mutations in the rpoB gene. *Frontiers in Microbiology*. 2016;7:999. DOI: 10.3389/fmicb.2016.00999. PMID: 27446039.

Commercial Biomedical Testing Module-3: Assessment of sclerostin antibody as a novel bone forming agent for prevention of spaceflight-induced skeletal fragility in mice (CBTM-3-Sclerostin Antibody) – Jonscher KR, Alfonso-Garcia A, Suhalim JL, Orlicky DJ, Potma EO, Ferguson VL, Bouxsein ML, Bateman TA, Stodieck LS, Levi M, Friedman JE, Gridley DS, Pecaut MJ. Spaceflight activates lipotoxic pathways in mouse liver. *PLOS ONE*. 2016;11(4):e0152877. DOI: 10.1371/journal.pone.0152877. PMID: 27097220.

Commercial Biomedical Testing Module-3: Assessment of sclerostin antibody as a novel bone forming agent for prevention of spaceflight-induced skeletal fragility in mice/ Commercial Biomedical Testing Module-3: STS-135 spaceflight's affects on vascular atrophy in the hind limbs of mice (CBTM-3-Sclerostin Antibody)/CBTM-3-Vascular Atrophy) – Ghosh P, Stabley JN, Behnke BJ, Allen MR, Delp MD. Effects of spaceflight on the murine mandible: Possible factors mediating skeletal changes in non-weight bearing bones of the head. *Bone*. 2016;83:156-161. DOI: 10.1016/j.bone.2015.11.001. PMID: 26545335.

RNA Interference and Protein Phosphorylation in Space Environment Using the Nematode *Caenorhabditis elegans* (CERISE) – Harada S, Hashizume T, Nemoto K, Shao Z, Higashitani N, Etheridge T, Szewczyk NJ, Fukui K, Higashibata A, Higashitani A. Fluid dynamics alter Caenorhabditis elegans body length via TGF-β/DBL-1 neuromuscular signaling. *npj Microgravity*. 2016;2:16006. DOI: 10.1038/npjmgrav.2016.6.

RNA Interference and Protein Phosphorylation in Space Environment Using the Nematode *Caenorhabditis elegans* (CERISE) – Higashibata A, Hashizume T, Nemoto K, Higashitani N, Etheridge T, Mori C, Harada S, Sugimoto T, Szewczyk NJ, Baba S, Mogami Y, Fukui K, Higashitani A. Microgravity elicits reproducible alterations in cytoskeletal and metabolic gene and protein expression in space-flown Caenorhabditis elegans. *npj Microgravity*. 2016;2:15022. DOI: 10.1038/npjmgrav.2015.22.

Growth and Survival of Colored Fungi in Space (CFS-A) – Gomoiu I, Chatzitheodoridis E, Vadrucci S, Walther I, Cojoc R. Fungal spores viability on the International Space Station. Origins of life and evolution of the biosphere: *The Journal of the International Society for the Study of the Origin of Life*. 2016;46(4):403-418. DOI: 10.1007/s11084-016-9502-5. PMID: 27106019.

Dynamism of Auxin Efflux Facilitators, CsPINs, Responsible for Gravity-regulated Growth and Development in Cucumber (CsPINs) – Yamazaki C, Fujii N, Miyazawa Y, Kamada M, Kasahara H, Osada I, Shimazu T, Fusejima Y, Higashibata A, Yamazaki TQ, Ishioka N, Takahashi H. The gravity-induced re-localization of auxin efflux carrier CsPIN1 in cucumber seedlings: spaceflight experiments for immunohistochemical microscopy. *npj Microgravity*. 2016;2:16030. DOI: 10.1038/npjmgrav.2016.30.

Lifetime Heritable Effect of Space Radiation on Mouse embryos Preserved for a long-term in ISS/Detection of Changes in LOH Profile of TK mutants of Human Cultured Cells/Gene Expression of p53-Regulated Genes in Mammalian Cultured Cells After Exposure to Space Environment/Study on the Effect of Space Environment to Embryonic Stem Cells to Their Development (Embryo Rad/LOH/RadGene/Stem Cells) – Ohnishi T. Life science experiments performed in space in the ISS/Kibo facility and future research plans. *Journal of Radiation Research*. 2016;57(Suppl 1);i41-i46. DOI: 10.1093/jrr/rrw020. PMID: 27130692.

EuTEF-Expose-Life – Brandt A, Posthoff E, de Vera JP, Onofri S, Ott S. Characterisation of growth and ultrastructural effects of the Xanthoria elegans photobiont after 1.5 years of space exposure on the International Space Station. Origins of life and evolution of the biosphere: *The Journal of the International Society for the Study of the Origin of Life*. 2016;46(2-3):311-321. DOI: 10.1007/s11084-015-9470-1. PMID: 26526425.

EuTEF-Expose-Life – Onofri S, de Vera JP, Zucconi L, Selbmann L, Scalzi G, Venkateswaran K, Rabbow E, de la Torre R, Horneck G. Survival of Antarctic cryptoendolithic fungi in simulated martian conditions on board the International Space Station. *Astrobiology*. 2015;15(12):1052-1059. DOI: 10.1089/ast.2015.1324. PMID: 26684504.

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International Space Station Internal Environments (ISS Internal Environments) – Willsey GG, Wargo MJ. Extracellular lipase and protease production from a model drinking water bacterial community is functionally robust to absence of individual members. *PLOS ONE*. 2015;10(11):e0143617. DOI: 10.1371/journal.pone.0143617. PMID: 26599415.

International Space Station Internal Environments (ISS Internal Environments) – Checinska A, Probst AJ, Vaishampayan PA, White JR, Kumar D, Stepanov VG, Fox GE, Nilsson HR, Pierson DL, Perry JL, Venkateswaran K. Microbiomes of the dust particles collected from the International Space Station and Spacecraft Assembly Facilities. *Microbiome*. 2015;3(1):50. DOI: 10.1186/s40168-015-0116-3. PMID: 26502721.

International Space Station Summary of Research Performed (ISS Summary of Research) – Vandenbrink JP, Kiss JZ. Space, the final frontier: A critical review of recent experiments performed in microgravity. *Plant Science*. 2016;243:115-119. DOI: 10.1016/j.plantsci.2015.11.004. PMID: 26795156.

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Transcriptome analysis and germ-cell development analysis of mice in the space (Mouse Epigenetics/JAXA Mouse Habitat Unit) – Shimbo M, Kudo T, Hamada M, Jeon H, Imamura Y, Asano K, Okada R, Tsunakawa Y, Mizuno S, Yagami K, Ishikawa C, Li H, Shiga T, Ishida J, Hamada J, Murata K, Ishimura T, Hashimoto M, Fukamizu A, Yamane M, Ikawa M, Morita H, Shinohara M, Asahara H, Akiyama T, Akiyama N, Sasanuma H, Yoshida N, Zhou R, Wang Y, Ito T, Kokubu Y, Noguchi TK, Ishimine H, Kurisaki A, Shiba D, Mizuno H, Shirakawa M, Ito N, Takeda S, Takahashi S. Ground-based assessment of JAXA mouse habitat cage unit by mouse phenotypic studies. *Experimental Animals*. 2016;65(2):175-187. DOI: 10.1538/expanim.15-0077. PMID: 26822934.

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Medaka Osteoclast – Murata Y, Yasuda T, Watanabe-Asaka T, Oda S, Mantoku A, Takeyama K, Chatani M, Kudo A, Uchida S, Suzuki H, Tanigaki F, Shirakawa M, Fujisawa K, Hamamoto Y, Terai S, Mitani H. Histological and transcriptomic analysis of adult Japanese medaka sampled onboard the International Space Station. *PLOS ONE*. 2015 October 1; 10(10): e0138799. DOI: 10.1371/journal.pone.0138799. PMID: 26427061.

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Microbial Dynamics in International Space Station - I (Microbe-I) – Ichijo T, Yamaguchi N, Nasu M. Bacterial monitoring in the International Space Station – “Kibo”. *Journal of Disaster Research*. 2015; 10(6): 1035-1039. DOI: 10.20965/jdr.2015.p1035.

Microbial Dynamics in International Space Station - I (Microbe-I) – Satoh K, Yamazaki TQ, Nakayama T, Umeda Y, Alshahni MM, Makimura M, Makimura K. Characterization of fungi isolated from the equipment used in the International Space Station or Space Shuttle. *Microbiology and Immunology*. 2016;60(5):295-302. DOI: 10.1111/1348-0421.12375. PMID: 26969809.

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NanoRacks-Comparison of the Growth Rate and DNA Characterization of Microgravity Exposed Microbial Community Samples (NanoRacks-Project MERCCURI) – Coil DA, Neches RY, Lang JM, Brown W, Severance MT, Cavalier D, Eisen JA. Growth of 48 built environment bacterial isolates on board the International Space Station (ISS). *PeerJ*. 2016;4:e1842. DOI: 10.7717/peerj.1842. PMID: 27019789.

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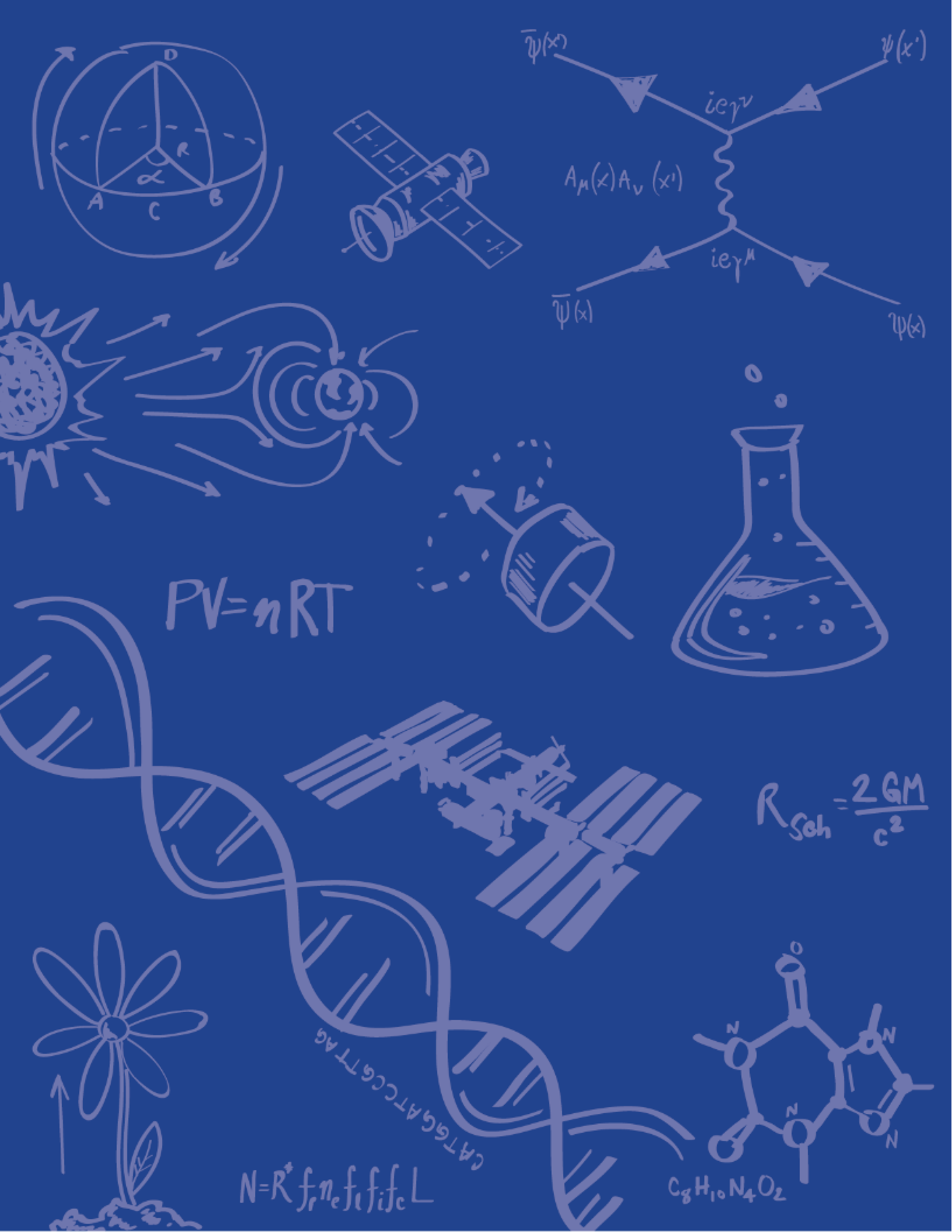

PV=nRT
R_Sch = 2GM/c^2
C8H10N4O2
N=R*frnefifific L